“State of the Technology”
Cellulosic Biofuels

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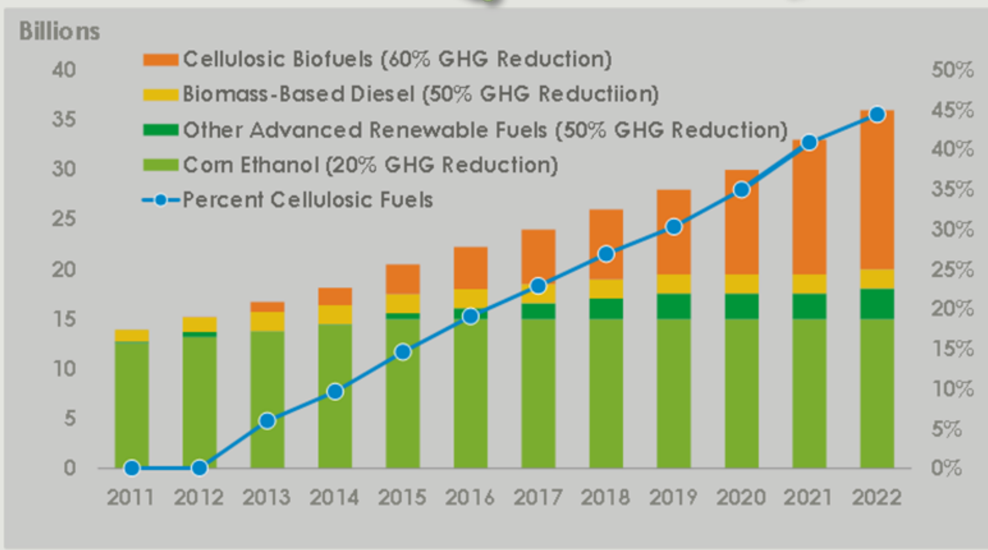
April 10, 2014

Cellulosic Opportunity

- Over 200 ethanol plants; current US demand of 14B gal/yr
- US Renewable Fuels Standard (RFS) requires additional sources of 16B gal/yr of cellulosic ethanol by 2022
  - ➢ **Cellulosic ethanol breakthroughs needed** to meet RFS intent and requirements
  - ➢ *Imports as alternative*
- RFS provides premium for cellulosic ethanol, forecast at ~$US 1.00/gal



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Cellulosic sugars are structural sugars found in fibrous biomass

Cellulosic sugars are widespread, but hard to extract

1st gen sugars

Corn, sugarcane

C6 sugars; easy to extract and ferment

(corn – dextrose; cane - glucose)

Cellulosic sugars

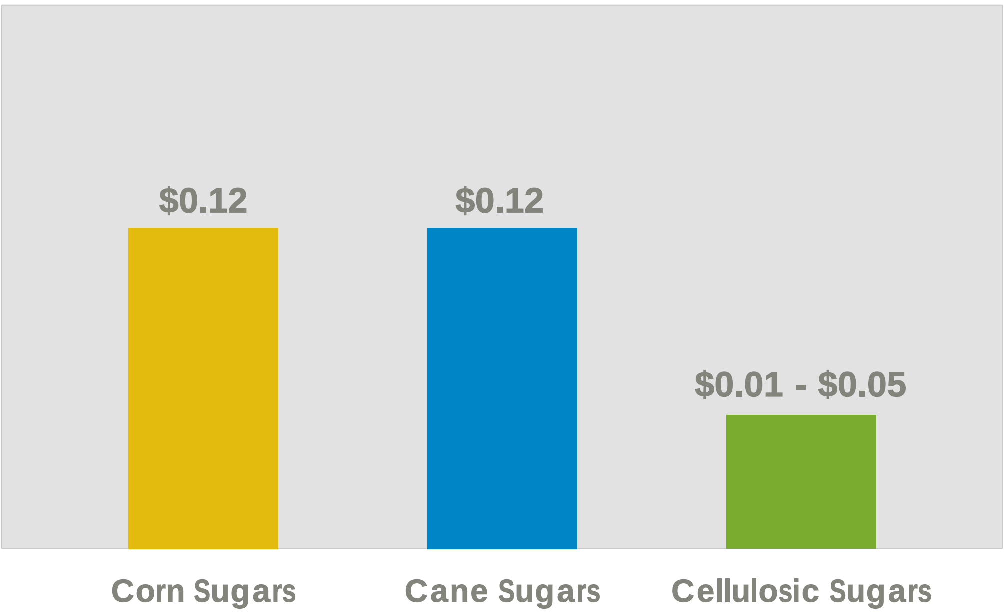
Corn stover, bagasse, wood

C6 sugars; harder to extract and less available

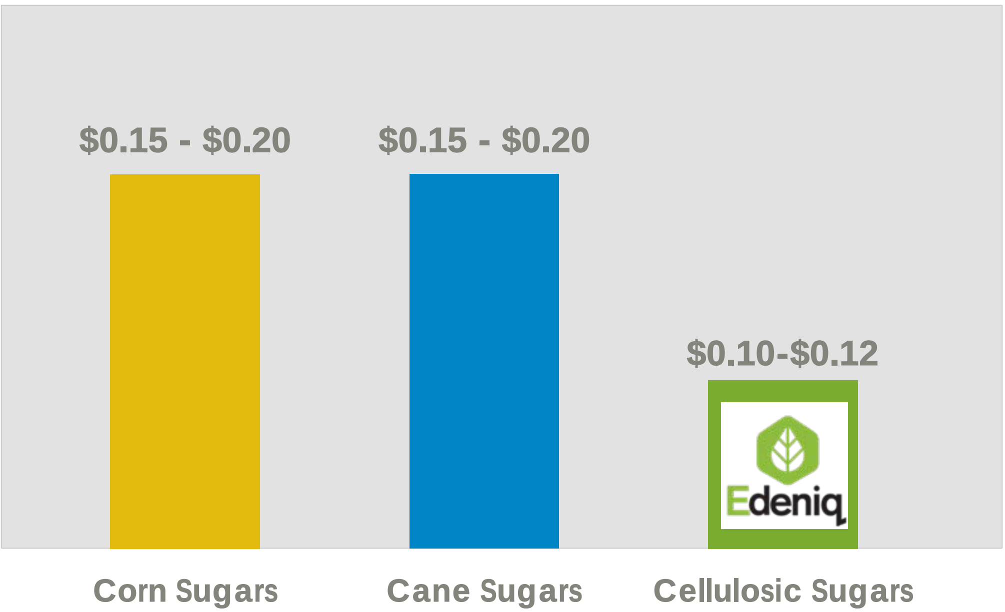
C5 sugars; hardest to extract and ferment

Cellulosic Sugars
Have Attractive Economics

Feedstock Costs
Per Lb.



Sugar Costs After Extraction
Per Lb.



Edeniq's Cellulosic Sugars will be cheaper than Corn and Cane Sugars

Challenge Areas

Focus must remain on key profitability barriers

Costs

- Capital
- Feedstock
- Enzymes/ Catalysts

Process Technology Limitations

- Conversion: process robustness, but..
- Purity: minimally invasive/ destructive (for downstream utility)

Feedstock Controversies

- Competition with food uses; alternative land uses

Investment Readiness Cycles

Status; Forward Priorities

Challenge Area: high capital costs

Current Approaches

- maximizing intensity of reactions (reduced volumes, times)
- maximizing utility of existing hardware (e.g., “bolt-on”)

Immediate Development Priorities

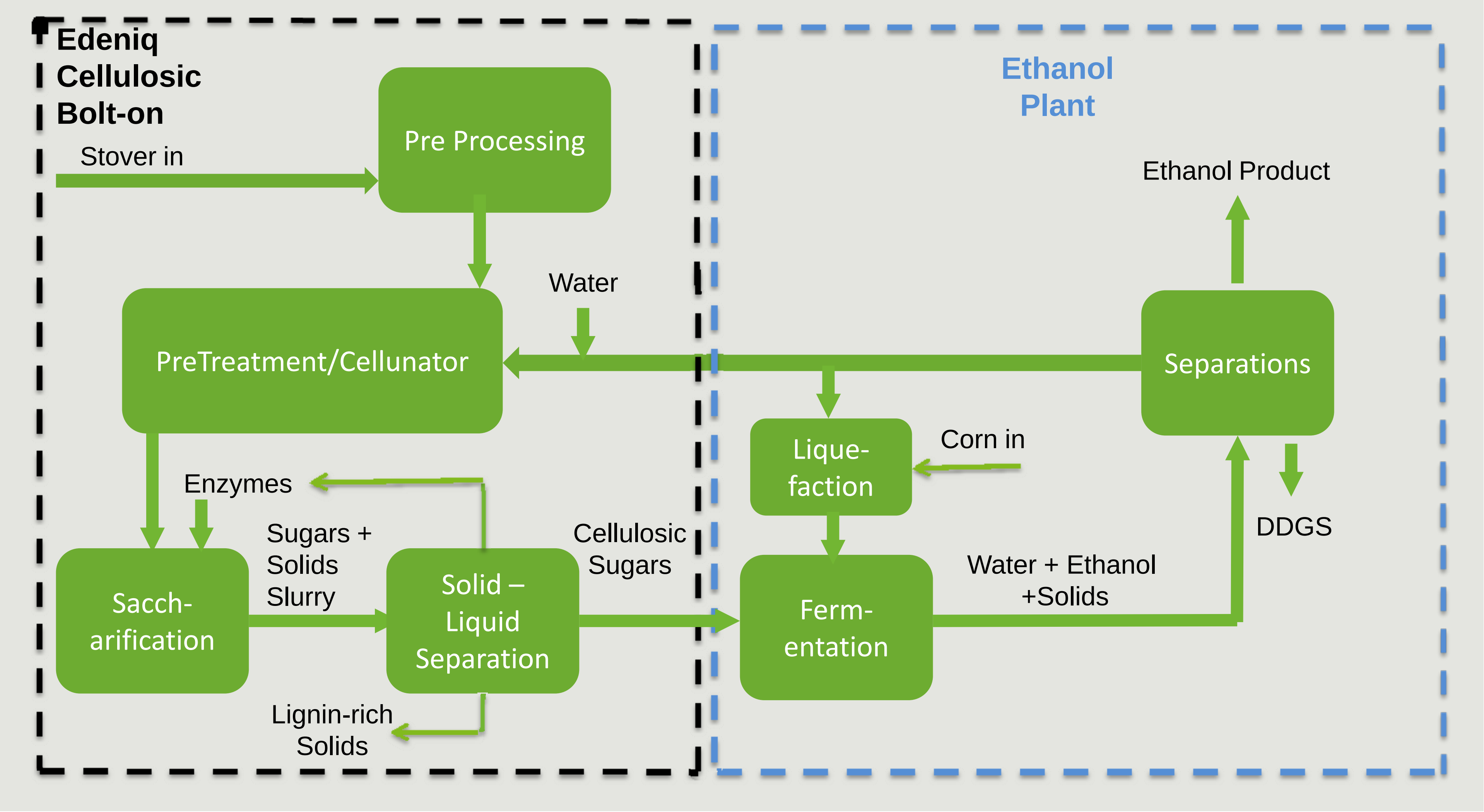
- increased solids loadings
- optimization of recycles

Recommendation for CEC Involvement

- fostering partnerships to facilitate technology linkages; unit operations and process equipment integration

Edeniq Bolt-On Design

Block Flow Diagram – Stover Integrated with Corn Ethanol Plant



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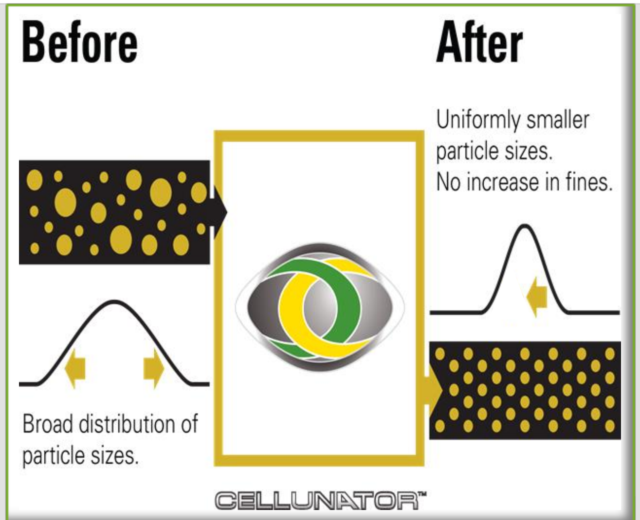
Edeniq's bolt-on technology:
Mechanical Pretreatment with Cellunator

- Wet state
- Right sizes particles
- Reduces viscosity
- Shears fiber
- Accessible enzymes to increased yield
- Homogeneous, stable, high-solids slurry



- Six Commercial Installations
  - ✓ Ethanol Facilities
  - ✓ 7+ years
  - ✓ 99.5% uptime
- Worldwide rights for biofuels and biomass markets
  - ✓ IKA Manufacture
- Patent No. 8,563,282
  - ✓ Granted Oct '13

Status; Forward Priorities

Challenge Area: high feedstock costs

Current Approaches

- looking for highest value compositions and consistency
- taking advantage of high-volume aggregation availability
- developing partnerships with expertise in both areas

Immediate Development Priorities

- deep understanding of physical and compositional variances
- process adaptability

Recommendation for CEC Involvement

- facilitating process integration partnerships
  (harvest protocols; pre-processing operations)

Edeniq-CEC
Feedstock Assessment Summary

Yields and Implications for California Feedstock Potential

Feedstock Class	Sugar Yield (kg/ton equiv)	Ethanol Potential (1) (gal/ ton)	Comments/ Other Factors
Nut Crop Residues	139	19	almond, peanut, walnut husks
Wood - Citrus	272	41	extensive work earlier in R&D pilot
Wood - Pine	133	19	useful cellulosic content low
Other Grain Crops (rice, milo) (2)	182 - 220	25 - 31	projections based on composition
Corn Stover	260 - 315	36 - 45	extensive CCM work with CA stover
Energy Cane (3)	460 - 518	66 - 75	cane bagasse

notes

1- assumes 92% efficiency of C6 fermentation; 75% for C5

2- high inorganic feedstocks; appear detrimental to Celluntor wear (separate tests)

3- surrogate for energy cane (CA programs in development)

- CA stover has high potential and is already available
- Energy crop projects appear to have the highest process potential; uncertain practicality due to land use issues
- Citrus wood is a possible target, but aggregation logistics uncertain
- Other feedstocks studied are disadvantaged

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Status; Forward Priorities

Challenge Area: high enzymes/ catalysts costs

Current Approaches

- engineering of process recycles; increased turnover numbers
- additives that enhance productivity and partitioning
- analytics to enable enzyme-specific improvement targets

Immediate Development Priority

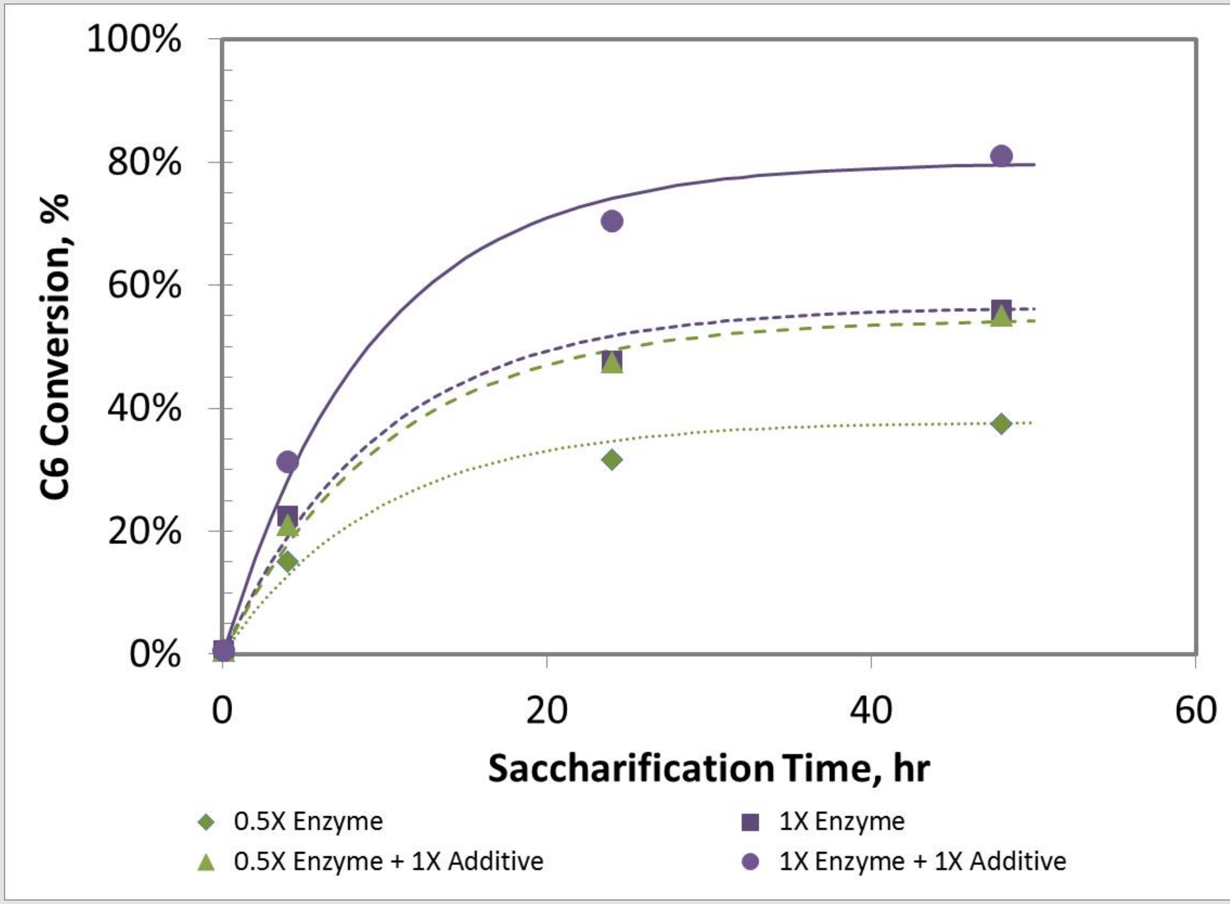
- demonstration of optimized enzyme deployment via advanced recycle strategies

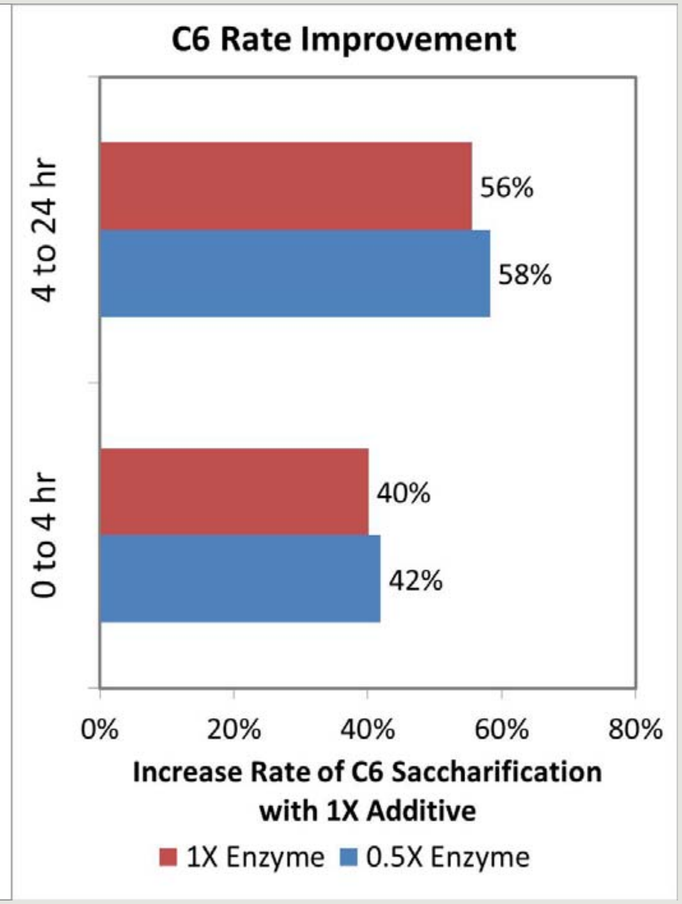
Recommendation for CEC Involvement

- support for analytical expertise development; fostering world-class, broadly available, enzymatic fundamentals resources

Proprietary Additives

- Proprietary additives increase C6 conversion
- Additives recovered and recycled in Edeniq process





Status; Forward Priorities

Challenge Area: Conversion; process robustness

Current Approaches

- intimate integration of pretreatment and hydrolysis; continuous processing
- advanced reactive separation engineering – capturing valuable intermediates while continuing to drive conversions

Immediate Development Priority

– optimization of operating space: conversion, purity, throughput – vs. capital requirements

Recommendation for CEC Involvement

- support for chemical reaction engineering expertise; extending feedstock studies to rheology (in process) studies

Hydrolysis Process Innovations

Proprietary continuous reactor

Cooperations with major suppliers to access latest enzymes

Edeniq has developed enzyme enhancers

- Increases activity of conventional enzymes
- Allows reduction in enzyme loadings
- R&D underway to improve performance

Enzymatic cocktails and process conditions optimized for each feedstock and process

Standard operating conditions

Saccharification yield targets

- C6: 80%
- C5: 70%

Optimizing enzyme recycle

Status; Forward Priorities

Challenge Area: Product quality; purity

Current Approaches

- benign preprocessing and pretreatment operations that are minimally destructive

  … retaining highest intermediate values

- focus on purity indices most critical to downstream processes

Immediate Development Priority

- optimized integration of all preprocessing and pretreatment unit operations

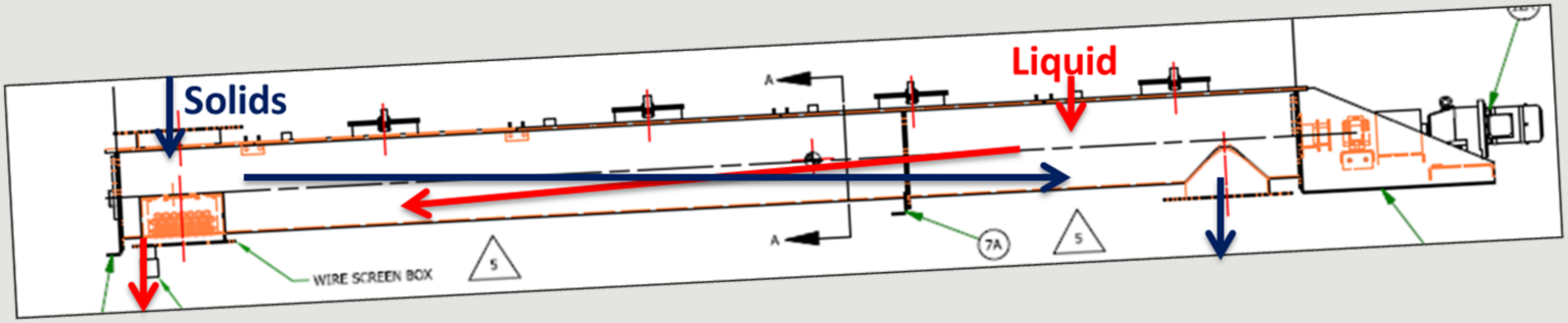
  … complete in-line processing

Recommendation for CEC Involvement

- support for differentiating equipment development;

  fostering world-class process engineering expertise resources

Hydrolysis Equipment Innovations



Tilted configuration of two-phase saccharification auger

SmartFlow TFF filter and housing assembly – in tandem with hydrolysis system operations

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Status; Forward Priorities

Challenge Area: Feedstock controversies

Current Approaches

- aggressive assessment of a wide range of non-food resources
- attention to holistic LCA assessments and C.I. rankings

Immediate Development Priority

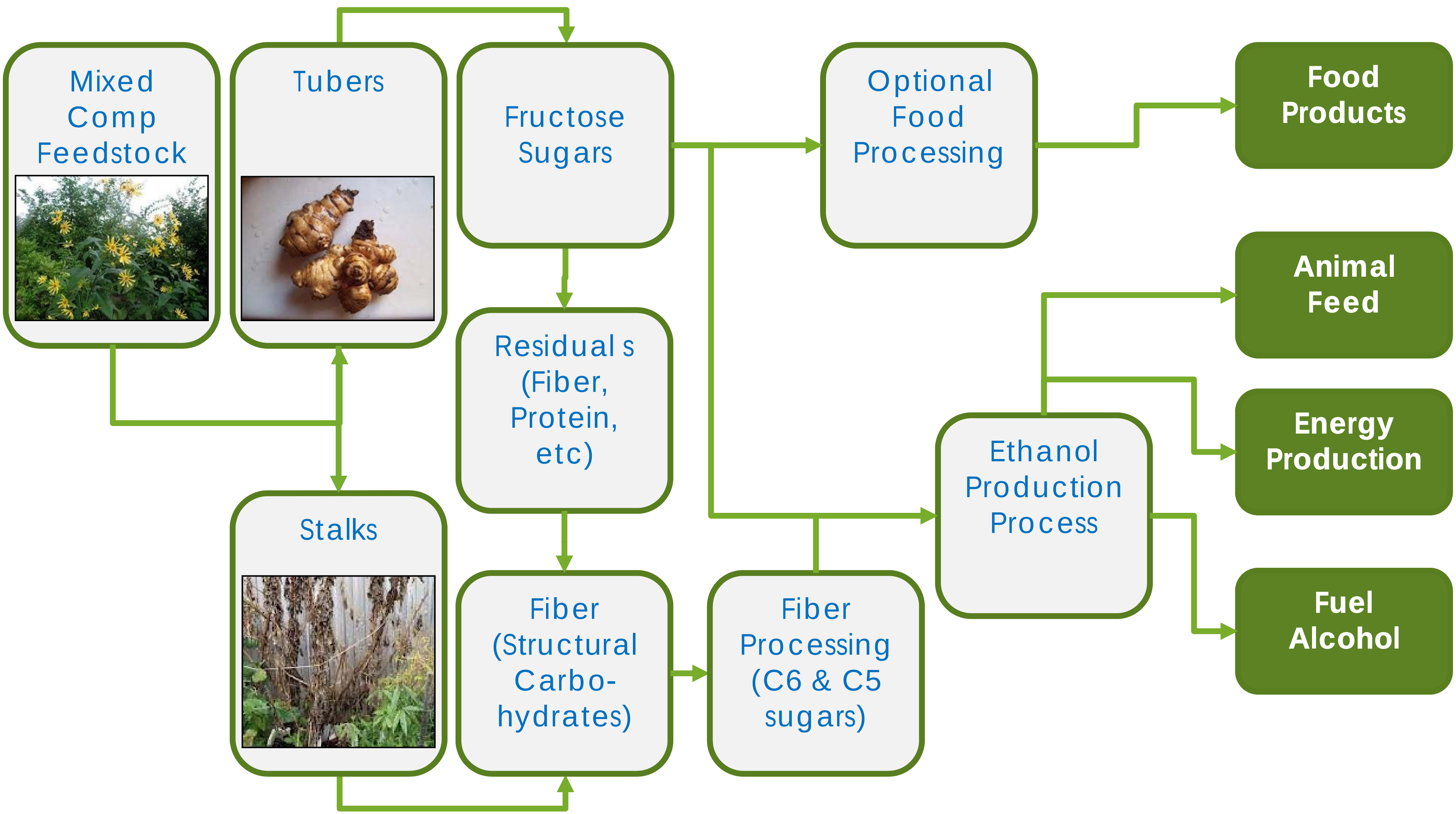
- extend “bolt-on” process configuration to a wide range of non-food, low C.I., economically-strategic feedstocks

Recommendation for CEC Involvement – support for step-wise technology roll-outs that will ultimately enable the most carbon-friendly scenarios; retention of expertise and focus on world-class LCA and C.I. assessment capabilities; enabling progressive feedstock acquisition partnerships that foster this expertise

Feedstocks Tested

- Sugar cane bagasse
- Corn Stover
- Wood chips (various types)
- Switchgrass
- Energy Cane
- High Biomass Sorghum
- With and without pelletization

Bolt-On Extension Example



Cellulosic Technology Features

Edeniq's Bolt-On Celluosics Process Incorporates Innovative Technology

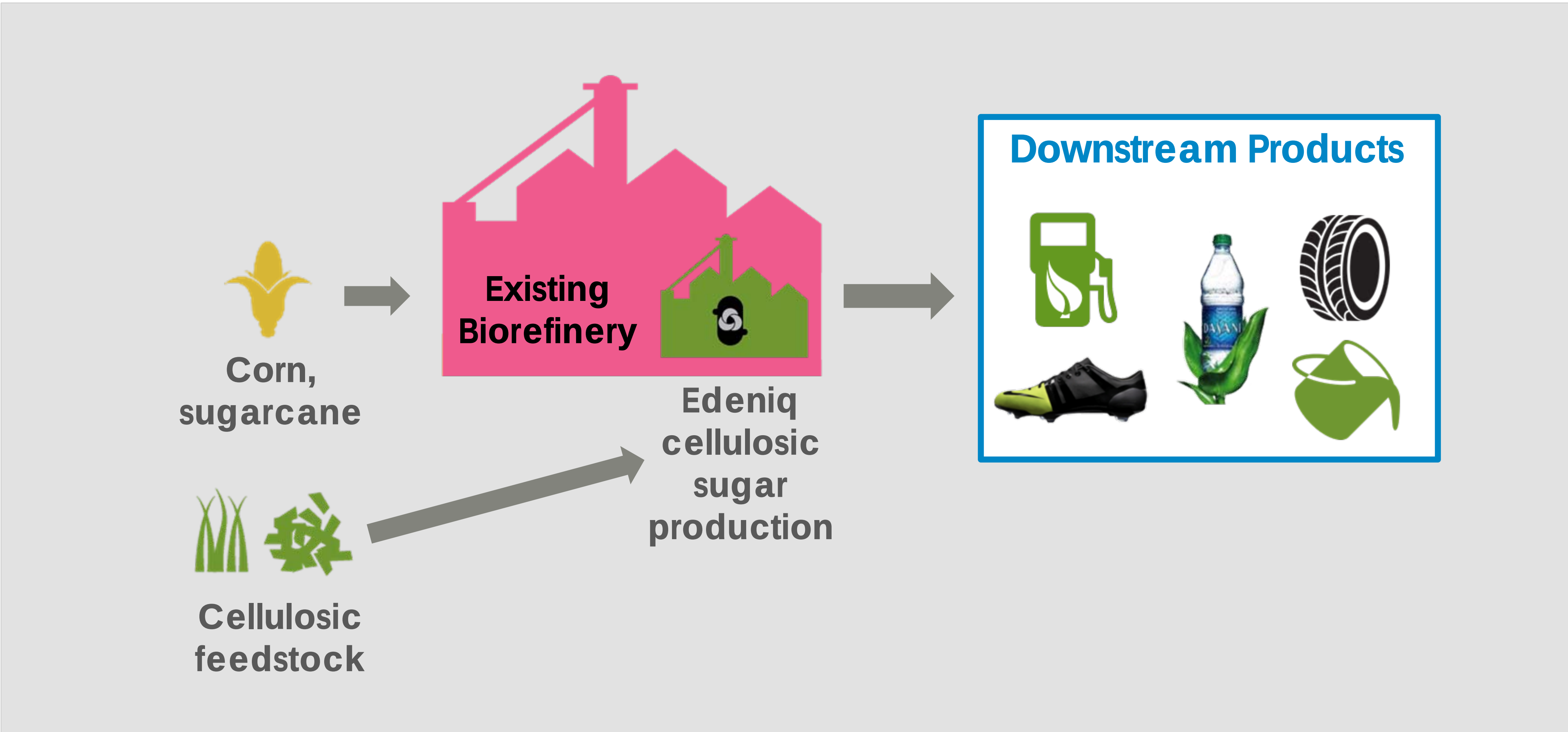
- **Fully continuous** pre-treatment and saccharification
- **Cellunator™** - and additional shear/ pretreatment elements
- Process to increase enzyme efficiency, **reduce enzyme costs**
- **SmartFlow** solid-liquid separation to produce solids-free sugars solution (exclusive license)
- **Leverage existing** fermentation, distillation capacities

Visalia pilot plant successes

- DOE-funded CCM plant **operational since March 2012** – up to 2 tpd
- Pretreatment **optimization to maximize conversions** in practical timescales
  - C_6 and C_5 saccharification ~75% maintained over extended periods
  - C_6 fermentation conversion >90% in <30 hrs
- Integrated process **water recovery and recycle fully operational**
- Simultaneous saccharification and fermentation feasibility proven
- **1500-hour DOE Performance Test** successfully completed – corn stover
- DOE targets of >1000 hrs; >90% up-time: **reached and exceeded**

- Operational parameters and baseline design kinetics established for scale-up to continuous processing and bagasse demonstrations
- Facility transitioned for validation of bolt-on commercial applications

Edeniq's bolt-on technology:
Integrating cellulosic sugars into existing biorefineries



Summary

Key Challenges Identified; Ongoing Support is Critical

- ✓ **Costs: Capital; Feedstock; Enzymes/ Catalysts**
- ✓ **Process Technology Limitations**
- ✓ **Feedstock Controversies**
- ? **Investment Readiness Cycles**

Support from the CEC – specifically via the ARFVTP – has been instrumental in forwarding these critical development programs.

Ongoing support is requested and recommended:

- establishment of **sustained core competencies**
- facilitation of **critical partnerships in the** value chain
- attacking identified **toughest technical issues** head-on
- continued emphasis on **holistic LCA evaluations**

Solution: Renewable fuel. Sugar is the new oil.

Oil Reserves

Biomass and Agriculture

Renewable and Secure

Unlocking the Sugar Conversion Process

Mechanical Processes

Technologies for Producing Lower Cost, High Purity Sugar

Biological Processes

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Enable Biorefineries to Become More Profitable and More Competitive